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AGARD Advisory Report No.259

**Technical Evaluation Report
on the
Guidance and Control Panel Symposium
on
Guidance and Control of
Precision Guided Weapons**

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NORTH ATLANTIC TREATY ORGANIZATION
ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT
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AGARD Advisory Report No.259
TECHNICAL EVALUATION REPORT
on the
GUIDANCE AND CONTROL PANEL SYMPOSIUM
on
GUIDANCE AND CONTROL OF PRECISION
GUIDED WEAPONS

by
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The Guidance and Control Panel 46th Symposium was held in Geilo, Norway from 3 to 6 May, 1988.
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PREFACE

The Guidance and Control Panel held a symposium on the topic of Precision Guided Munitions in Norway in 1982. Due to the rapid advance in guidance and control technology for such weapons, and because the body of engineering experience with such weapons is growing, it is appropriate to review these advances.

The content of the 46th GCP symposium included the broad range of precision guided weapons against beyond-visual-range surface targets (moving or not) and helicopters with emphasis on guidance and control aspects of such weapons, and, where appropriate, their airborne or ground platforms.

Topics covered included:

- Acquisition and guidance sensors;
- Target signatures;
- Guidance and control algorithms and software;
- Command and control, targetting and launch considerations as they apply to guidance and control;
- Integration issues such as guidance and fuzing;
- Countermeasures versus guidance techniques: trends.

* * *

En 1982, en Norvège, le Panel du Guidage, et du Pilotage avait organisé un symposium sur le thème des armes guidées de précision.

Les progrès réalisés dans la technologie du guidage et du pilotage de telles armes depuis cette date, et l'expérience croissante acquise par les ingénieurs, justifient la réactualisation de ces progrès.

Le Programme du 46ème Symposium du GCP couvre l'ensemble des armes guidées de précision déployées contre les cibles au-delà de la portée optique (mobiles ou non) y compris les hélicoptères, et met l'accent sur les aspects guidage et pilotage de telles armes et, quand cela s'avère nécessaire, sur leurs plate-formes au sol ou aéroportées.

Les sujets traités comprennent:

- Capteurs d'acquisition et de guidage;
- Signatures d'objectif;
- Algorithmes et logiciels de guidage et de pilotage;
- Commandes de vol et de pilotage, acquisition d'objectifs, considérations concernant le guidage et le pilotage;
- Les questions d'intégration, telles que le guidage et la mise à feu des fusées de proximité;
- Contre-mesures opposées aux techniques de guidage; tendances.

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Le Panel tient à remercier les Délégués Nationaux de la Norvège près l'AGARD de leur invitation à tenir cette réunion dans leur pays et de la mise à disposition de personnel et des installations nécessaires.

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EXECUTIVE SUMMARY

The 46th symposium of the AGARD Guidance and Control Panel (GCP) was convened in Geilo, Norway 3-6 May 1988 on the topic "Guidance and Control of Precision Guided Weapons". This was the first revisit of the topic since a GCP symposium in 1982.

The symposium covered a broad range of precision guided weapons against beyond-visual-range targets (moving or not) and helicopters, with emphasis on guidance and control of such weapons, and, where appropriate, their airborne or ground platforms. A variety of sensors and control mechanisms were described which are focused on the anti-armor low cost precision munitions problem.

The robustness of all-weather applications continues to drive system designers to desire multi-mode sensors for target identification and terminal guidance, but the costliness of such systems for anti-armor ordnance has yet to be resolved.

Imaging systems still remain the favorite of the technologists, but issues of targeting, aspect dependence, and the overwhelming costs of identification algorithms and other image processing problems remains an insufficiently defined domain for the system designer to seriously consider robust autonomous imaging for low cost systems. There needs to be considerable more research and analysis in this area.

Finally, an observation concerning the character of GCP symposia: because the GCP tends to function as a systems panel for AGARD, each of its symposia is tending to be very broad. Although this is necessary from the systems view, it appears that significant areas of technology do not receive the in-depth treatment desired by some of the technical community.

INTRODUCTION

The 46th symposium of the AGARD Guidance and Control Panel (GCP) was convened in Geilo, Norway 3-6 May 1988. This symposium was on the topic "Guidance and Control of Precision Guided Weapons".

The GCP held a symposium on the same general theme in 1982. Coincidentally, that symposium was also hosted by Norway. In the TER for the 1982 symposium, it was concluded that the technology and applications could be expected to advance rapidly; it was recommended that the GCP re-visit the topic in no more than three years. The press of the variety of topics of interest to the GCP precluded such a quick return to the topic, the GCP agreed that the topic was due a re-examination in 1988.

As stated by the Program Committee in its proposal to the National Delegates Board and in the Call For Papers for this symposium, it was considered appropriate to review guidance and control of precision guided weapons because of "the rapid advance in guidance and control technology for such weapons, and because the body of engineering experience with such weapons is growing".

The stated purpose of the symposium was to include the broad range of precision guided weapons against beyond-visual-range targets (moving or not) and helicopters, with emphasis on guidance and control of such weapons, and, where appropriate, their airborne or ground platforms.

The symposium keynote address and welcome was presented by H.K. Johansen, the AGARD national Delegate from Norway. He remarked that the 1982 symposium on this topic had also been hosted by Norway. He spoke of the importance of programs in this weapons area both militarily to NATO on the whole and industrially to countries such as Norway, which has a strong PENGUIN program in this area.

Mr. Johansen underscored the need for less costly NATO alternatives to aircraft for some missions in the face of a more effective Warsaw Pact air defense. He called for advanced seekers to discriminate against jamming, and higher capacity seeker processing for terrain following and greater attack flexibility, such as aiming for the most vulnerable point on the target. He particularly noted the opportunity for saturating enemy defenses if weapons could be made in sufficiently low cost to acquire in large numbers.

The Chairman of the symposium, Mr. H. Radet added in his remarks that such weapons were of increasing importance in the post-INF environment.

SESSION I: OPERATIONAL REQUIREMENTS AND CONSIDERATIONS

This session was intended to explore some fundamental considerations for operation of precision guided weapons and to expose the operational requirements for such weapons.

Several papers satisfied the first objective. A fundamental examination of multipath phenomena presented both phase and amplitude characteristics at millimeter-wave frequencies (SNEIDER et al.). Experimental results presented for asphalt, concrete and snow surfaces showed multipath to be a serious parameter for low altitude flight against ground targets where the grazing angle of multipath reflection is small.

The paper just discussed served as the fore-runner of a discussion of theoretical radar cross-sections of valuable installations at NATO airfields (SNEIDER et al.), supplemented by experimental measurements. Practical suggestions for reducing target signature (e.g., changing the 90-degree dihedral of some structures) are to be demonstrated through flight tests against modified structures.

Two papers described the measurement of target signatures of ground armor at 94 GHz, with consideration of the interaction between signature, wave form, and seeker-tracker characteristics. One set of measurements were more thorough in examining various target aspects from a fixed tower (GRUENER), while the other concentrated on measurements from aircraft to obtain more realistic signature profiles in time (DE COZ et al.).

A proposal was made for a development of a generic 94 GHz system based on feature extraction (edges for navigation, image energy for armor detection). The claim was advanced (AGNEL et al.) that feature reference maps could be prepared rapidly from a variety of sources using the "invariant characteristics" of the target, although the author did not demonstrate that there were such characteristics. The claim was made that the described technique would be more robust, but the author did not describe how to deal with aspect dependent navigation and target features.

A double-length paper described a wide-ranging U.S. program called the Balanced Technology Initiative (SNOWDEN). Many of the programs listed had relevance to the theme of the symposium, and most were of interest to advancing conventional tactical warfare. Regrettably, so many projects were listed as a part of the program that there was no time for the author to describe the technologies with which each deals. Nevertheless, the catalogue of projects is useful as a reference for pursuing details of projects of interest.

In summary, Session I as executed was somewhat uneven in concept. Although many of the papers did not deal explicitly with operational requirements or considerations, most were solidly grounded in an understanding of the requirements or in expanding knowledge of the operational environment.

The session could have been sharpened by a paper or two on the operational emphasis from the NATO military point of view.

SESSION II: GUIDANCE SENSORS AND COMPONENTS

In this session, the symposium moved briskly into more focused engineering issues. A variety of sensors was described in this session, both external active and passive target detectors and inertial components for self-contained guidance.

A sensor was described (GAY et al.) which uses a common infrared detector for both passive detection and active detection and imaging when used with a carbon dioxide laser. Classification capabilities were also claimed for the program, but technical details of that part of the system were beyond the scope of the paper. Impressive video tapes demonstrated the imaging capabilities of the sensor suite.

Another combination sensor consisted of an FM CW 35 GHz radar (HOLPP). The detector could also be used as a passive radiometer, although the advantage of that mode seemed marginal even if the added cost were small.

An airborne acoustic armor detection sensor array (GROBECKER et al.) was an interesting variation from the usual electromagnetic detection technique. Although the problem of acoustic noise from the reciprocating engine of the host RPV had been effectively dealt with, the problem of aerodynamic self-noise of the microphones in the airstream remained a problem.

An AM CW diode laser and PIN detector was described (SEPP et al.) as a flexible anti-helicopter fuzing device. Test data showed the ability to distinguish between helicopters and fixed wing aircraft because the rotating helo blades "chop" the laser return.

In the search for small gyros for gun-launched guided projectiles, a survey of various technologies was presented (CHAILLOT). It was posited that acoustic or double resonator piezoelectric gyros should more promise than laser or fiber-optic gyros in obtaining the desired 1 cc. volume.

Indicating the state of the art in low cost inertial sensors for guided shells, a fiber-optic gyro at 4 cc. (BUESCHELBERGER et al.), and an accelerometer at 2 cc. (BOURA et al.) were described.

This session was quite successful in describing an interesting range of potential sensors, ranging from the precise (and probably expensive) to determined attempts to lower the cost of sensors for guided munitions.

SESSION III: GUIDANCE & CONTROL TECHNIQUES AND SIGNAL PROCESSING

This session dealt with guidance and control issues in the fire-and-forget mode as well as with externally controlled guidance.

Analysis for an infrared guided shell favored an initial pursuit mode to reduce get the seeker angle after ballistic flight, followed by pursuit guidance (WALTHER et al.). A generic analysis of the footprint of guided shells against ground armor examined the trade-off between skid-to-turn and bank-to-turn control (DAMEN). The conclusion was that skid-to-turn was more robust, especially against moving targets. The author described several attempts to modify bank-to-turn to improve the footprint; these attempts were successful to the degree that the modification approached skid-to-turn.

A concept for a ship self-defense missile used a laser command link which could be used as a beam rider as well, with high explosive strips along the shell side to effect in-flight maneuvers. This paper (LEVY) concentrated on the control algorithm for precision guidance with the few explosive strips, and included a thorough rationale for a multi-shot strategy to effectively use the system features.

An extensive examination (GRINNAKER), apparently in its early stages, of image processing for a variety of guidance and control functions (mid-course map-matching, target tracking, classification, aimpoint selection) underscored the computational intensity of this technology. This paper served to illuminate the advances in processing and feature recognition techniques which must occur before application to the low cost end of the weapons spectrum with which the conference dealt.

Man-in-the-loop control was the concern of a simulation of FOG-M footprint using a 3-D model board (VAN GENT et al.). The experiments re-emphasized the usefulness of joy-stick feedback to the operator, a requirement which was established in the earliest phases of manned aircraft fly-by-wire.

This session was rich in variety of control mechanizations for the PGM problem. Missing, however were papers with signal processing detail.

SESSION IV: EFFECTIVENESS AND SYSTEM EVALUATION

System effectiveness of PGM's in tank-and-helo against tank-and-helo using a computer war game simulation (GRENARD et al.) evaluates a cost function involving cost of rounds and reconstitution costs. The author was not specific how to overcome the need for many simulations to converge on a cost given the large number of variables for each game.

Relative effectiveness of millimeter wave and infrared were examined for autonomous search on a submunitions bus (BLAKE et al.), with the conclusion that a dual seeker is most advantageous for weather and countermeasure robustness. The authors concluded that a mixed load on the bus would be more cost effective than a dual seeker, but neither operational nor cost analyses were presented to support this conclusion.

A program to validate a comprehensive infrared simulator system (BART et al.) using a variety of flight test data will make this simulator an effective device for exploring infrared system issues.

Two papers were beyond the theme of this session: one described the inflight alignment algorithm for the PENGUIN missile on a LAMPS helicopter; the other showed a straight-forward statistical technique for determining aimpoint distribution based on operational parameters, eliminating the necessity of assuming (incorrectly) the independence of probabilities of detection, hit, and kill.

SESSION V: SYSTEMS DEMONSTRATION

A concept for a stand-off weapon to be used against helicopters was described (JACOBS) from its genesis in the FOG-M program. A film demonstration of the digital correlator for azimuth stabilization was shown, using hovering and flying helos as targets.

The other paper in this session (DUKE) was intended to show the effectiveness of the several candidates for a line-of-sight defense system where the stressing target is

the hovering helo in clutter. Unfortunately, only one set of experiments had been cleared for presentation, so that a comparison could not be shown. The test results for the single example were sufficient to show the breadth of operational conditions which were examined in the demonstrations.

ROUND TABLE DISCUSSION

A round table discussion featuring the chairman of the symposium and his session chairmen provided a thoughtful coda, raising unresolved issues and a few warnings.

A central issue of the discussion was properly related to cost. High costs of infrared detector arrays and multi-mode systems were a concern. It was noted that the Soviets seemed to use various versions of weapons with different modes rather than either single mode or multi-mode guidance.

There was a distinct difference of opinion as to whether emphasis should be on the use of existing technology in innovative ways or whether investment was required in new sensor technologies.

The general dearth of development money was seen as having specific impact on systems capability improvement and cost reduction. Although experience with "non-development item" procurement seems satisfactory, it was remarked that "up-front money" was required to make significant reductions in costs of autonomous weapons.

The trend to remove processing from the weapon was marked as a general trend to reduce cost, but the question was posed whether man-in-the-loop systems might not require so much training as to reduce the net cost savings achieved in acquisition.

REACTION OF THE SYMPOSIUM PARTICIPANTS

The attendees at the symposium seemed generally pleased with the technical and administrative aspects of the conference. Specific responses were obtained from some 40 standard questionnaires returned by the attendees. These responses are summarized as follows:

	Most	About Half	Very Few
Did papers meet objective of symposium?	85%	15%	---
Topics selected were of interest to you?	43%	52%	5%

Over 87% of the responders judged the depth of presentation and the time allowed for discussion to be satisfactory.

95% of the responders rated the symposium on the whole as "Good" or better, with over 50% rating the symposium as "Very Good" or "Excellent".

A few offered mild complaints about the isolation of the site; this reporter believes that much more effective interaction is obtained among attendees if a site without distractions, yet with room and services to make for comfort. The Geilo site and the Highlands Hotel admirable satisfied these criteria.

SYMPOSIUM ADMINISTRATION

Symposium management was up to the best standards of AGARD, and reflected admirably on the host country as well. There were two items worth mentioning for future reference, however.

First, the security sign-in procedure is something which must be endured by the attendees, and AGARD staff are usually effective and efficient at this necessary but thankless job. On one morning of the symposium, insufficient security staff were available, and many attendees complained about the slowness of receiving badges for the day, and the session chairman was required to slow the proceedings accordingly.

Second, the inexorable shift to videotapes to support presentations was a new source of technical difficulty for the support staff. Some equipment difficulties occurred in nearly every presentation which used video. Of the two video sets used in the conference hall, it seemed that only one was operating properly at any given time. The nature of the problem was not obvious, indicating that particular care and planning is necessary on the part of host and AGARD staff to check video capabilities well in advance.

CONCLUSIONS AND RECOMMENDATIONS

The degree of authority with which the various authors rationalized their programs indicated the serious interest of the NATO forces in pursuing precision guided weapons, particularly for line-of-sight and beyond-line-of-sight use against armor and supporting helicopters.

In most of the papers, a careful regard for cost was apparent. This was particularly so in descriptions of advances in individual sensors, where costs continue to steadily decrease. The robustness of all-weather applications continues to drive system designers to desire multi-mode sensors for target identification and terminal guidance, but the costliness of such systems for anti-armor ordnance has yet to be resolved.

As a near term solution, use of the man-in-the-loop has emerged using fiber-optics as the link medium. There is promise of this extending into automatic but not autonomous systems, where the costly processing is retained on the ground or in the aircraft launch platform. This development may be the touchstone for affordable multi-mode systems. This line of research should be vigorously pursued.

Finally, an observation concerning the character of GCP symposia: because the GCP tends to function as a systems panel for AGARD, each of its symposia is tending to be very broad. Although this is necessary from the systems view, it appears that significant areas of technology do not receive the in-depth treatment desired by some of the technical community. For example, this symposium might have concentrated on target signatures, sensor suites, and sensor signal and image processing; this would have provided more technical depth in these areas, and still would have been of interest to system designers.

The question of balance between technical issues and systems issues will continue to be a problem for the GCP as it attempts to strike a balance among its responsibilities, particularly in the weapons area.

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